CHAPTER 2: GEOLOGIC HAZARDS

2.1 Physiographic Setting

The City of Glendale is located at the southeasternmost edge of the San Fernando Valley, in an area characterized by sharp contrasts in terrain. Distinct topographic features separate the City into four specific areas. From north to south these include 1) the steeply rising range front of the San Gabriel Mountains, 2) the gently south-dipping but elevated alluvial fan surface known as the La Cañada Valley at the base of the San Gabriel Mountains, 3) the lower but not less impressive bedrock highlands of the Verdugo Mountains and the San Rafael Hills, and 4) the even more gently south-dipping alluvial surface (piedmont) at the base of the Verdugo Mountains. Farther south, just outside the City limits, is the northeastern end of the Santa Monica Mountains, which are locally referred to as the Hollywood Hills. The Los Angeles River hugs the north side of the Hollywood Hills as it flows easterly through the area; when it reaches the eastern end of the hills, the river veers south to flow through the "Narrows" and the City of Los Angeles on its way to the Pacific Ocean. The two heavily populated alluvial surfaces at the base of the Verdugo and San Gabriel Mountains are linked by the south-trending canyon carved by the Verdugo Wash that separates the Verdugo Mountains on the west from the San Rafael Hills on the east.

Elevations in the southern part of the City range from about 420 feet above mean sea level at the southernmost point to about 800 feet at the base of the Verdugo Mountains. Mount Verdugo reaches an elevation of 3,126 feet, while the top of Flint Peak in the San Rafael Hills sits at an elevation of 1,889 feet. In the San Gabriel Mountains, the highest point within the City is at an elevation of about 4,800 feet.

The steep southern flank of the San Gabriel Mountains is deeply incised by gorges and canyons that drain south into the La Cañada Valley, where they have been channelized, conveying their flows south to Verdugo Wash. The three canyons that are located mostly within City limits include Ward, Dunsmore, and Cooks. Several other streams draining the San Gabriel Mountains that are also channelized through the La Crescenta area and into the northern portion of Glendale; these include the Eagle Canyon, Pickens, Hills and Winery Canyon channels. Refer to Chapter 3 and Plate 3-1 for additional information and the location of these landforms. Nearly all the tributaries flowing northerly and easterly out of the Verdugo Mountains and westerly out of the San Rafael Hills also empty into Verdugo Wash. South of the mountains, Verdugo Wash turns to the west-southwest and joins the Los Angeles River near the junction of Highway 134 with the 5 Freeway (Interstate 5). Drainage from the southwestern slope of the Verdugo Mountains flows directly across the alluvial fan and into the Los Angeles River. As discussed further in Chapter 3, Verdugo Wash has been confined to a man-made channel through most of Glendale to reduce the potential for it to flood the City.

2.2 Geologic Setting

The physical features described above reflect geologic and climatic processes that have effected this region in the last few million years. The most striking geologic features of the Glendale area are the Verdugo and San Gabriel Mountains, which form a dramatic backdrop to the southern and northern portions, respectively, of the City. These rugged, geologically young mountains are part of the Transverse Ranges Province of southern California. The characteristic features that define this province are a series of predominantly east-west trending mountain ranges and their intervening valleys. The ranges encompass the northern part of Los Angeles County as well as parts of Riverside, San Bernardino, Ventura, and Santa Barbara counties, and extend offshore, forming submarine canyons and ridges, in addition to the Channel Islands.

The San Gabriel Mountains are located in the central part of the Transverse Ranges, where they rise abruptly to heights of more than 7,000 feet above the valley floor (several peaks are more than 9,000 feet high and Mount Baldy is the highest at 10,064 feet). Bounded by the San Andreas fault system on the north and the Sierra Madre fault zone on the south, the mountains are essentially a large block of the Earth's crust that has been squeezed up and thrust over the valley floor by north-south compression along the Big Bend portion of the San Andreas tectonic plate boundary. Tectonic forces that initiated the rise of the mountains are thought to have started about 3.5 million years ago, at a time when scientists now believe there was a change in the relative motion of the Pacific and North American tectonic plates from strike-slip (slipping horizontally past one another) to transpressive (oblique movement that is a combination of strike-slip and compression). Uplift of the mountains accelerated in mid-Pleistocene time, about 500,000 years ago, and continues today (Wright, 1991). The current rate of uplift, in the context of geologic time, is one of the fastest in the world.

Displacements on faults at the northern edge of the Los Angeles Basin, in the San Fernando and San Gabriel Valleys, are mainly of the thrust or thrust-oblique type, causing older geologic units to be pushed up along a series of faults that dip northward beneath the mountains they have formed (see Plate 1-2). The most dramatic example of this in the Glendale area is the Sierra Madre fault zone, which has thrust ancient crystalline rocks onto and over younger sediments filling the valley. The Verdugo Mountains are also a prominent feature on the Glendale skyline. These mountains are separated from the San Gabriel mountain front by the La Cañada Valley ("cañada" is the Spanish word for valley, gorge, or ravine), but are composed of crystalline rocks similar to those exposed in the San Gabriel Mountains (Jennings et al., 1977; Dibblee, 1989a, 1991a, 1991b). During the mid Miocene (approximately 15 million years ago), the Glendale area was a region of low relief, but the same tectonic forces that gave rise to the San Gabriel Mountains also thrust the basement rocks up to form the present Verdugo Mountains (R.T. Frankian & Associates, 1968). This uplift is thought to have occurred along the Verdugo fault, which is identified by the juxtaposition of Cretaceous quartz diorite bedrock against Quaternary alluvial fan deposits along the southwestern front of the Verdugo range. Some researchers have suggested that vertical separation on this fault may be at least 3,300 feet (1,000 m) (Tsutsumi and Yeats, 1999). Not only was the bedrock uplifted, but it seems that the entire bedrock block was tilted to the north, as evidenced by the consistently north- to northeast-dipping fabric of the rock exposed in the Verdugo Mountains. More recently, the Verdugo fault is thought to be primarily a strike-slip fault (Walls et al., 1998; Dolan, personal communication, 2002).

Also in recent years, researchers have discovered that the Los Angeles metropolitan area is underlain by a series of deep-seated, low-angle thrust faults. When these faults do not reach the surface, they are called "blind thrusts". Faults of this type are thought to be responsible for the uplift of many of the low hills in the Los Angeles Basin, such as the Elysian Park, Repetto, and Montebello Hills (Dolan et al., 2001). Previously undetected blind thrust faults were responsible for the M5.9 Whittier Narrows earthquake in 1987, and the destructive M6.7 Northridge earthquake in 1994.

Strike-slip faults are also present in the northern Los Angeles basin, and where they have been most recently active, they have deformed the landscape and altered drainage patterns. An example of such faulting near the Glendale area is the Raymond fault, a predominantly left-lateral fault that is responsible for the string of low hills and knolls that disrupt the gently sloping valley floor near the southeastern edge of the City (Weaver and Dolan, 2000). The Raymond fault is an active structure that is thought to have been the source of the 1988 Pasadena earthquake (Jones et al., 1990). The relationship between the two styles of fault movement (thrust and strike-slip) is complex and not well understood. Consequently, it is currently one of the focus points in the ongoing research for a greater understanding of earthquake hazards in the Los Angeles basin (Dolan et al., 2001).

The San Rafael Hills are the southeastern extension of the Verdugo Mountains and are similarly separated from the San Gabriel Mountains by the La Cañada Valley. In their central and northern parts, the San Rafael Hills are composed of crystalline rocks similar to those exposed in the San Gabriel and Verdugo Mountains. However, the Eagle Rock fault, which traverses the southern part of the hills, forms the geologic boundary between crystalline rocks to the north and Miocene-age sedimentary rocks forming the low hills to the south.

The La Cañada Valley and the valley south of the Verdugo Mountains are infilled with alluvial fan sediments shed off the rising mountains. As a result, the composition of these alluvial deposits reflects that of the rocks eroded by the various streams emanating from the mountains. Multiple generations of overlapping alluvial fans are present, with older sediments occurring at depth, and younger deposits occurring near the top of the section. Deposition is still ongoing, and as a result, the alluvial sediments exposed at the ground surface are very young. As discussed in Section 1.7, and covered further in this chapter, the age of these alluvial sediments controls to some extent the engineering properties of the materials, and also determines their susceptibility to liquefaction, settlement, and other seismic and geotechnical hazards. Remnants of older surfaces are present locally near the base of the mountains, north of the Sierra Madre fault, where movement on the fault has elevated the alluvial deposits above the area of active deposition. Older alluvial sediments also occur locally in the Verdugo Mountains and San Rafael Hills, on the sides of canyons.

2.3 Geologic Units

The general distribution of geologic units that are exposed at the surface in the Glendale area is shown on the Geologic Map (Plate 2-1). In the numerous geologic maps that have been published over the years for this area, there are inconsistencies in the nomenclature used for faults and geologic formations. In the section that follows, the characteristics of each unit are discussed using the names published by Dibblee (1989a, 1989b, 1991a, 1991b, 2002). Descriptions of the units, as well as some of their engineering characteristics, are compiled from R.T. Frankian & Associates (1968), Lamar (1970), Morton (1973), Crook et al. (1987), Dibblee (1989a, 1989b, 1991a, 1991b, 2002), and the California Geological Survey (CDMG, 1998a, 1998b, 1998c). The units are described, from the youngest to the oldest, in the following sections. Fault names are those published primarily by Weber (1980), Dibblee (1989a, 1989b, 1991a, 1991b), Yerkes (1997), Yerkes and Graham (1997), and Envicom (1975).

2.3.1 Surficial Sediments

Researchers use the degree of soil development on surfaces, stratigraphic position, degree of stream incision, relative uplift, and mineral composition to estimate the age of alluvial deposits. If organic materials, such as charcoal, are found in the deposits, then the age of these sediments can be determined with more certainty using radiocarbon dating techniques. Other absolute age dating techniques for sediments, such as optical thermoluminescence, are slowly becoming more commonplace. The age estimates given below for the alluvial units in Glendale are based on a combination of techniques that different researchers have used to interpret the geologic history of the area.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

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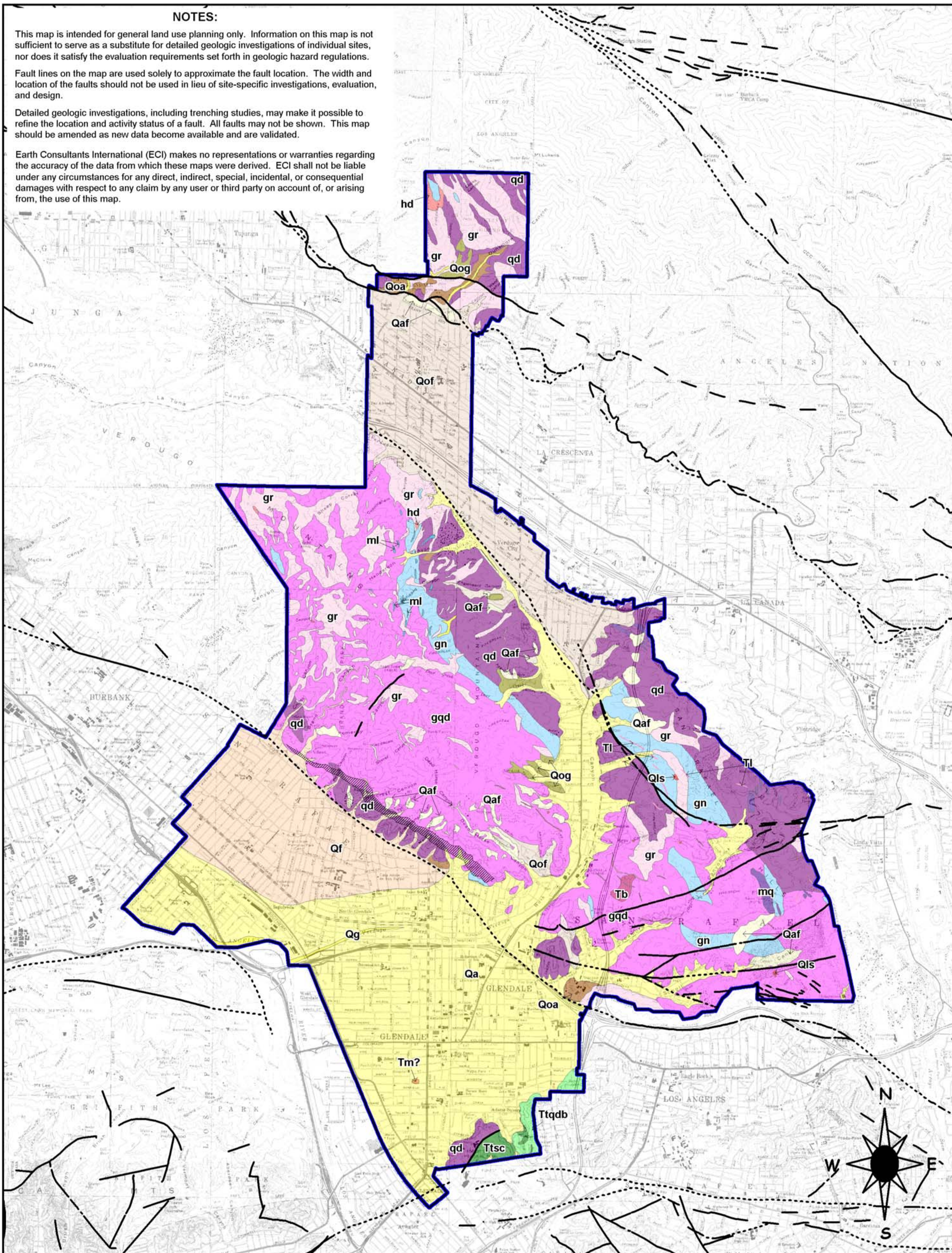

Scale: 1:60,000

1000 0 1000 2000 3000
Meters

5000 0 5000 10000 15000
Feet

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Weber, 1980; Dibblee, 1989a, 1989b, 1991a, 1991b, 2002; Rubin, 1992; Yerkes, 1997; Yerkes and Graham, 1997; Byer, 1968.

CITY OF GLENDALE CALIFORNIA

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Geologic Map

Glendale, California

Plate 2-1

SYMBOLS

Fault; solid where location known, dashed where approximate, dotted where concealed, hatchured where defined as zone, (for more information refer to Plate 1-2).

Glendale City Boundary

Geologic Contact

GEOLOGIC UNIT DESCRIPTIONS

Surficial Sediments

Quaternary	Holocene	Qaf	Artificial fill
Quaternary	Holocene	Qg	Stream channel deposits of gravel, sand and silt.
Quaternary	Holocene	Qa	Alluvium; unconsolidated floodplain deposits of silt, sand and gravel.
Quaternary	Holocene	Qf	Alluvial Fan
Quaternary	Holocene	Qls	Mapped Landslide

Older Dissected Surficial Sediments

Quaternary	Pleistocene	Qoa	Remnants of older weakly consolidated alluvial deposits of gravel, sand and silt.
Quaternary	Pleistocene	Qof	Alluvial fan gravel and sand derived from San Gabriel Mountains; includes some Qg and Qa in northern areas.
Quaternary	Pleistocene	Qog	Elevated remnants of alluvial gravel and fanglomerate deposits, weakly indurated; in San Gabriel Mountain foothills partly weathered reddish; in that area may locally include Pacoima and Saugus Formation of Smith (1986).

Monterey Formation

Tertiary	Miocene	Tm?	White-weathering, thin bedded, platy siliceous and semi siliceous rocks.

Topanga(?) Formation

Tertiary	Miocene	Ttqdb	Gray to brown breccia, massive to vaguely bedded, composed of angular detritus and a few rounded cobbles and boulders, all of biotite horblende quartz diorite.
Tertiary	Miocene	Ttsc	Light gray to brown, semi-friable sandstone, and interbedded brown sandy to silty shale, semisiliceous shale, and pebble-cobble conglomerate of quartz diorite detritus; Luisian(?) stage.

Dike Rocks

Tertiary	Miocene	Tb	Thin dikes of black to brown, fine-grained basaltic to andesitic intrusive rocks.
Tertiary	Miocene	Tl	Thin dikes of light gray latite porphyry.

Granitic Rocks

Mesozoic	gr	Gray-white, medium- to fine-grained massive granitic rock mostly of quartz monzonite and granodiorite composition; composed essentially of quartz, plagioclase feldspar (oligoclase), K-feldspar (mostly microline) and minor biotite.

Quartz Diorite

Mesozoic	qd	Gray, medium-grained quartz diorite to diorite, massive, non-gneissoid quartz diorite composed essentially of plagioclase feldspar (oligoclase-andesine, hornblende, biotite, and minor quartz); incoherent where weathered.
Mesozoic	gqd	Gray, medium-grained quartz diorite to diorite, massive to gneissoid quartz diorite, composed essentially of plagioclase feldspar (oligoclase-andesine, hornblende, biotite, and minor quartz); incoherent where weathered.

Hornblende-Diorite

Paleozoic or Older	hd	Dark gray, massive to locally gneissoid, medium-grained diorite-gabbro composed m of hornblende and plagioclase feldspar (andesine); locally includes lenses of hornbl biotite-rich layered gneiss.

Siliceous Metamorphic Rocks

Precambrian (?)	mq	Gray, banded fine-grained siliceous rock; probably metaquartzite or metachert.

Gneissic Rocks

Precambrian (?)	gn	Gray banded biotite-rich quartz plagioclase gneiss; in part contorted, migmatized wit quartz diorite (qd) and complexly intruded or injected by leucogranitic rocks (gr).
Precambrian (?)	ml	Small lenses of white layered marble and associated clac-silicate rocks.

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Explanation of Geologic Map

Plate 2-1a

The youngest and most widely exposed alluvial units in the Glendale area consist of Holocene (about 10,000 years old and younger) channel and floodplain deposits derived from the Verdugo Mountains and the San Rafael Hills, and from the Hollywood Hills south and west of the Glendale area. The sediments have been transported from the base of the slopes to the piedmont surfaces by the streams that drain these highlands, that is, the tributaries to Verdugo Wash and Verdugo Wash itself. A large portion of the City is situated on these young deposits.

Older fan deposits form as an elevated, moderately to highly dissected surface near the San Gabriel Mountains range front, in the La Cañada Valley area. Limited exposures of this unit are also present as isolated terraces above active stream channels within the San Gabriel and Verdugo Mountains, and within deeply incised drainage channels where they are visible in the sidewalls below the younger units. Even older alluvial deposits occur locally on the uplifted side (north) of the active Sierra Madre thrust fault. The estimated age for these older sediments in the San Gabriel Mountains is about 200,000+ years (Crook et al., 1987).

Artificial Fill (map symbol Qaf) – Artificial fill occurs in small patches at the base of the San Gabriel Mountains and within canyons of the Verdugo Mountains and San Rafael Hills. The deposits in the San Gabriel and Verdugo Mountains consist primarily of engineered fill that has been compacted and is suitable for development. This type of fill lines the bottom of canyons and is used for residential developments, road beds, and flood control structures. Interstate Highway 210 is also built on engineered fill where it passes through the northern portion of Verdugo Canyon. In the San Rafael Hills, artificial fill that has been compacted to lower densities (not suitable for building foundations) is used for the Scholl Canyon Golf Course and Scholl Canyon Park. Many other areas of artificial fill, too small to show on the geologic map, are present in the City.

Holocene Alluvium (map symbols Qg and Qa) – This group includes modern stream channel and fan deposits (Qg), as well as slightly older floodplain deposits (Qa). Within the City of Glendale, the youngest alluvial unit (Qg) has been mapped in and immediately adjacent to the channel of the Los Angeles River, and in the lower-most reaches of the Verdugo Wash, just before it empties into the Los Angeles River. These sediments are not present in the central and upper reaches of the Verdugo Wash because sediment deposition in this area is now largely contained by the debris basins and man-made channels that have been built in the last about 50 to 70 years. The Qg deposits consist of unconsolidated, poorly sorted, white to gray, silt, sand and gravel. These deposits lack development of a soil profile at or near the ground surface, indicating their youthfulness. Their density has been described as very loose to loose.

The older (Qa) unit is the most extensive deposit in the study area, underlying most of southern Glendale, the Verdugo Wash canyon, and the central and lower reaches of several of the tributaries to Verdugo Wash. Qa deposits also underlie the small uplifted valley that dissects the southern part of the San Rafael Hills. In most areas, this unit consists of fluvial and alluvial fan deposits of unconsolidated, gray to olive brown, silt, fine to coarse sand, and gravel. Mid to late Holocene in age (approximately 5,000 years old and younger), these deposits have been slightly elevated above the modern drainage courses. The gravels are typically subangular to rounded, and are generally unweathered. Soil development in this unit is limited to a poorly developed A horizon. In the southern portion of the San Rafael Hills, this deposit consists primarily of silty and clayey sand with interbedded clay. The density of these deposits has been described as loose to medium dense.

The oldest Holocene unit (Qf) consists of alluvial fan deposits shed off the Verdugo Mountains and deposited at the base of the range front. This unit consists primarily of pale yellowish brown sandy layers with lesser amounts of matrix-supported pebble- to cobble-sized gravel. The compositions of the clasts include granite, quartz diorite, schist, crystalline limestone, and quartzite. These sediments are generally unconsolidated and show minimal soil development, as evidenced by a few buried A horizons and some possible buried B horizons (Dolan and Tucker, 1999).

***Pleistocene Dissected Alluvium (map* symbols: Qoa, Qof and Qog**) – The youngest Pleistocene unit that crops out in the study area (Qoa) consists of uplifted remnant alluvial fan deposits. Small patches of Qoa, approximately 1/2 acre in area, are located on both sides of Verdugo Wash, on the north side of the Verdugo fault, and at the San Gabriel range front, on the uplifted (north) side of the Sierra Madre fault zone. These alluvial fan deposits are characterized by weakly consolidated deposits of gravel, sand, and silt.

The next oldest unit (Qof) underlies most of the developed area of north Glendale and consists of mid-Pleistocene alluvial fan deposits shed from the San Gabriel Mountains and dissected by modern drainages. These deposits consist primarily of yellowish brown to pale brown silt, sand, and silty sand with little to no clay. The alluvium has been described as dense and weakly to moderately well consolidated. Near the mountain front, these deposits consist of crudely bedded sand and gravel with large boulders. Where undisturbed, this unit has a poorly to moderately developed soil profile which includes an A horizon and textural B horizon.

Most of the oldest alluvial deposits (Qog) have been removed by erosion or concealed by deposition of younger sediments. Exposures are limited to a few remnants uplifted above the bottom of Verdugo Canyon at the eastern end of the Verdugo Mountains. This unit consists of red to yellow, poorly consolidated to well-consolidated fine to coarse sand, silty sand, and gravel. Clay content varies from low to high. This unit has been extensively dissected by both large and small drainages, and typically has a well developed soil profile. Gravels within the unit are highly weathered.

Landslide Debris (map symbol Qls) - Three small landslides (Qls) of probable Holocene age have been mapped on the slopes of the Verdugo Mountains and the San Rafael Hills (see Plates 2-1 and 2-4). Because the bedrock in these areas is highly fractured and weathered, the slides consist of small blocks and rock fragments rather than large cohesive masses. The Qls deposits are discussed in more detail in the landslide hazards section below (Section 2.4.1).

2.3.2 Bedrock Units

Within Glendale, areas of high relief are underlain primarily by a complex assemblage of crystalline rocks created from multiple episodes of igneous intrusion and metamorphism deep within the Earth's crust. This association represents a long history of such events, and includes some of the oldest rocks (dating back to the Precambrian age) in southern California. The contacts between rock types are approximate and somewhat variable in geologic maps published over the years, reflecting the difficulty of mapping in rugged, brush-covered terrain, as well as identifying rock types that are highly shattered, sheared, and crushed. Many map units include more than one rock type, and the predominant rock type has typically been used to characterize the unit. One unit, the leucocratic granodiorite, occurs as dikes and irregular-shaped lenses intruding into the various different units southwest of the South Branch of the San Gabriel fault. The youngest bedrock unit consists of sedimentary rock formed from deep marine deposits that encroached onto the area where Glendale is now located prior to uplift of the present Verdugo and San Gabriel Mountains.

Topanga Formation (map symbol: Ttqdb and Ttsc) - The Miocene age Topanga Formation underlies the low hills at the southern edge of the City. This sedimentary rock unit is separated from the crystalline rocks of the San Rafael Hills by the Raymond fault. In the Glendale area, the Topanga Formation consists of two primary components: a light gray to brown sandstone interbedded with a lesser amount of shale and conglomerate (Ttsc), and a massive to vaguely bedded breccia with lenses of silty shale and sandstone (Ttqdb). Bedding character is typically crudely developed to massive in the conglomerate beds, whereas it is well developed in the finer grained sequences. Sedimentary structures within the deposits have led scientists to believe these sediments were deposited in a deep marine environment with a not too distant source (Lamar, 1970). This unit is folded, and bedding dips generally in the range of 20 to 30 degrees to the west and north, although both flatter and steeper dips have been measured locally (Dibblee, 1989a, 1989b).

Dike Rocks (map symbol: Tb and Tl) – These units occur as widely scattered, tabular bodies of igneous rock within older rocks of the Verdugo Mountains and the San Rafael Hills. The dikes typically formed by intrusion of magma into fractures and joints of the existing rocks. In the Glendale area, the dikes are fine-grained and consist of brown to black rocks of basaltic and andesitic composition (Tb), as well as pale gray rocks composed of light-colored minerals (Tl). The dikes are thought to be late Miocene in age, or older.

Leucocratic Granitic Rocks (map symbol: gr) – This unit includes light colored, fine- to medium-grained rocks composed primarily of quartz, plagioclase and potassium feldspars, with minor biotite. It occurs as bands and patches across the base of the San Gabriel Mountains, and as intrusive dikes into the older quartz diorite rock within the Verdugo Mountains and San Rafael Hills. This unit is exposed at a few sites along Verdugo and Sycamore Canyons. This unit is thought to be Cretaceous or Jurassic in age, but may be older.

Quartz Diorite (map symbol: qd and gqd) - Sometimes referred to as the Wilson Diorite, this unit is the most widespread bedrock type in the Glendale area. The bulk of the Verdugo Mountains and the San Rafael Hills are comprised of quartz diorite. The color of the rock is typically a light gray to light brown, and the minerals that form the rock include plagioclase feldspar, hornblende, biotite and quartz. The texture is generally medium grained and the structure is massive (qd). In the central part of the San Rafael Hills, just north of Highway 134, at the southeastern margin of Glendale, the mineral grains are aligned, giving the rock a distinct banding or "foliation" (qqd). This is called a "gneissoid" texture due to its similarity to gneiss, a relatively common metamorphic rock. The foliation gives the rock a somewhat layered structure, and in this area, that structure dips 60 to 70 degrees to the east and northeast. A similar structure is observed in the Verdugo Mountains, except that the foliation dips steeply to the east, and the orientation changes from northwesterly in the southern part of the mountains, to northerly in the northern part of the range (R.T. Frankian & Associates, 1968). The contact between the massive and foliated units is gradational. This rock is highly fractured and generally deeply weathered, making it friable (grains disaggregate easily) near the surface. This unit is approximately 122 million years old, based on actual dating of bedrock samples, and is therefore early Cretaceous in age (Larsen, 1958).

Hornblende Diorite-Gabbro (map symbol: hd) – Within City limits, this rock type crops out in a few small isolated areas in the northern part of Hahamongna Watershed Park. The rock is medium-grained and massive, but locally has a gneissoid structure. The rock is dark gray in color because it is rich in dark minerals such as hornblende and biotite.

Siliceous Metamorphic Rocks (map symbol: mq) – These rocks are rare within the City, occurring only locally in a few small isolated areas in the San Rafael Hills. As described by Smith (1986), this unit consists of medium gray, fine-grained to microcrystalline, banded, siliceous rock, probably metachert. It is estimated to be Paleozoic in age, but may be as old as Precambrian.

Gneissic Rocks (map symbol: gn and ml) – These are the oldest and most lithologically complex rocks that crop out in the Glendale area. The rocks are exposed as irregular patches in the San Rafael Hills and the Verdugo Mountains, and consist primarily of quartzofeldspathic gneiss (gn). Small lenses of white, layered marble and calc-silicate (ml) occur within these rocks in the central portion of the Verdugo Mountains. These rocks are complexly intruded by younger granitic rocks. The gneissic rocks are generally well-banded, and moderately to well-foliated. The foliation dips primarily to the northeast at 30 to 80 degrees (Dibblee, 1991a, 1991b).

2.4 Geologic Hazards in the Glendale Area

2.4.1 Landslides and Slope Instability

Nearly half of the land in Glendale consists of steep hillslopes and rugged mountains. These areas have for the most part been preserved in their near natural state, while most of the development in the City occurs in the flat to gently sloping alluvial surfaces at the base of the mountains. However, some development (primarily residential) is present in and adjacent to steep hillsides. These areas include the canyons within the Verdugo Mountains and the San Rafael Hills, and the alluvial fans situated at the front of the San Gabriel and Verdugo Mountains (see Plate 2-2). Such areas are locally vulnerable to slope instability, particularly in winters of heavy rainfall and in winters following wildfires.

Careful land management in hillside areas can reduce the economic and social losses caused by slope failures. This generally includes land use zoning to restrict development in unstable areas, grading codes for earthwork construction, geologic and soil engineering investigations and reviews, construction of drainage structures, and where warranted, placement of warning systems. Other important factors are risk assessments (including susceptibility maps), a concerned local government, and an educated public.

TYPES OF SLOPE FAILURES

Slope failures occur in a variety of forms and there is usually a distinction made between gross failures (sometimes also referred to as "global" failures) and surficial failures. Gross failures include deep-seated or relatively thick slide masses, such as landslides, whereas surficial failures can range from minor soil slips to destructive debris flows. Slope failures can occur on natural or man-made slopes. Most failures of man-made slopes occur on older slopes, many of which were built at slope gradients steeper than those allowed by today's grading codes. Although infrequent, failures can also occur on newer graded slopes, generally due to poor engineering or poor construction. Slope failures often occur as elements of interrelated natural hazards in which one event triggers a secondary event, such earthquake-induced landsliding, fire-flood sequences, or storm-induced mudflows.

Gross Instability

Landslides - Landslides are movements of relatively large land masses, either as nearly intact bedrock blocks, or as jumbled mixes of bedrock blocks, fragments, debris, and soil. The type of movement is generally described as translational (slippage on a relatively planar, dipping layer), rotational (circular-shaped failure plane) or wedge (movement of a wedge-shaped block from between intersecting planes of weakness, such as fractures, faults and bedding).

The potential for slope failure is dependent on many factors and their interrelationships. Some of the most important factors include slope height, slope steepness (Plate 2-2), shear strength and orientation of weak layers in the underlying geologic unit (see Plate 2-3), as well as pore water pressures. Joints and shears, which weaken the rock fabric, allow water to enter the bedrock mass leading to deeper weathering of the rock, along with increased pore pressures and increased weight of the landmass. Water also increases the plasticity of weak clays lining the joints or shears, forming planes of weakness along which the landmass can fail. Ultimately, all of these conditions can cause the slope to fail.

For engineering of earth materials, these factors are combined in calculations to determine if a slope meets a minimum safety standard. The generally accepted standard is a factor of safety of 1.5 or greater (where 1.0 is equilibrium, and less than 1.0 is failure). Although existing landslides are not widespread in the Glendale area, it is probable that many of the steeper hillsides do not meet the minimum factor of safety, and slope stabilization may be needed if development reaches these areas. Natural slopes, graded slopes, or graded/natural slope combinations must meet these minimum engineering standards where they impact planned homes, subdivisions, or other types of developments. Slopes adjacent to areas where the risk of economic losses from landsliding is small, such as parks and mountain roadways, are often allowed a lesser factor of safety. From an engineering perspective, landslides are generally unstable (may be subject to reactivation), and may be compressible, especially around the margins, which are typically highly disturbed and broken. The headscarp area above the landslide mass is also unstable, since it is typically oversteepened, cracked, and subject to additional failures.

Surficial Instability

Slope Creep - Slope creep in general involves deformation and movement of the outer soil or rock materials in the face of the slope, due to the forces of gravity overcoming the shear strength of the material. Soil creep is the imperceptibly slow and relatively continuous downslope movement of the soil layer on moderate to steep slopes. Creep is most common in soils that develop on fine-grained bedrock units. Rock creep is a similar process, and involves permanent deformation of the outer few feet of the rock surface, resulting in folding and fracturing. Rock creep is most common in highly fractured, fine-grained rock units, such as siltstone and claystone, but also occurs in highly fractured crystalline rock. In fact, studies of prehistoric landslides in the San Gabriel Mountains suggest that creep can weaken steep rock slopes to the point where toppling failure (essentially a large slide consisting of angular blocks of rock) can occur (Rodgers et al., 1992).

Creep also occurs in graded fill slopes. This process is thought to be related to the alternate wetting and drying of slopes constructed with fine-grained, expansive soils. The repeated expansion and contraction of the soils at the slope face leads to loosening and fracturing of the soils, thereby leaving the soils susceptible to creep. While soil creep is not catastrophic, it can cause damage to structures and improvements located at the top of the slope.

NOTES:

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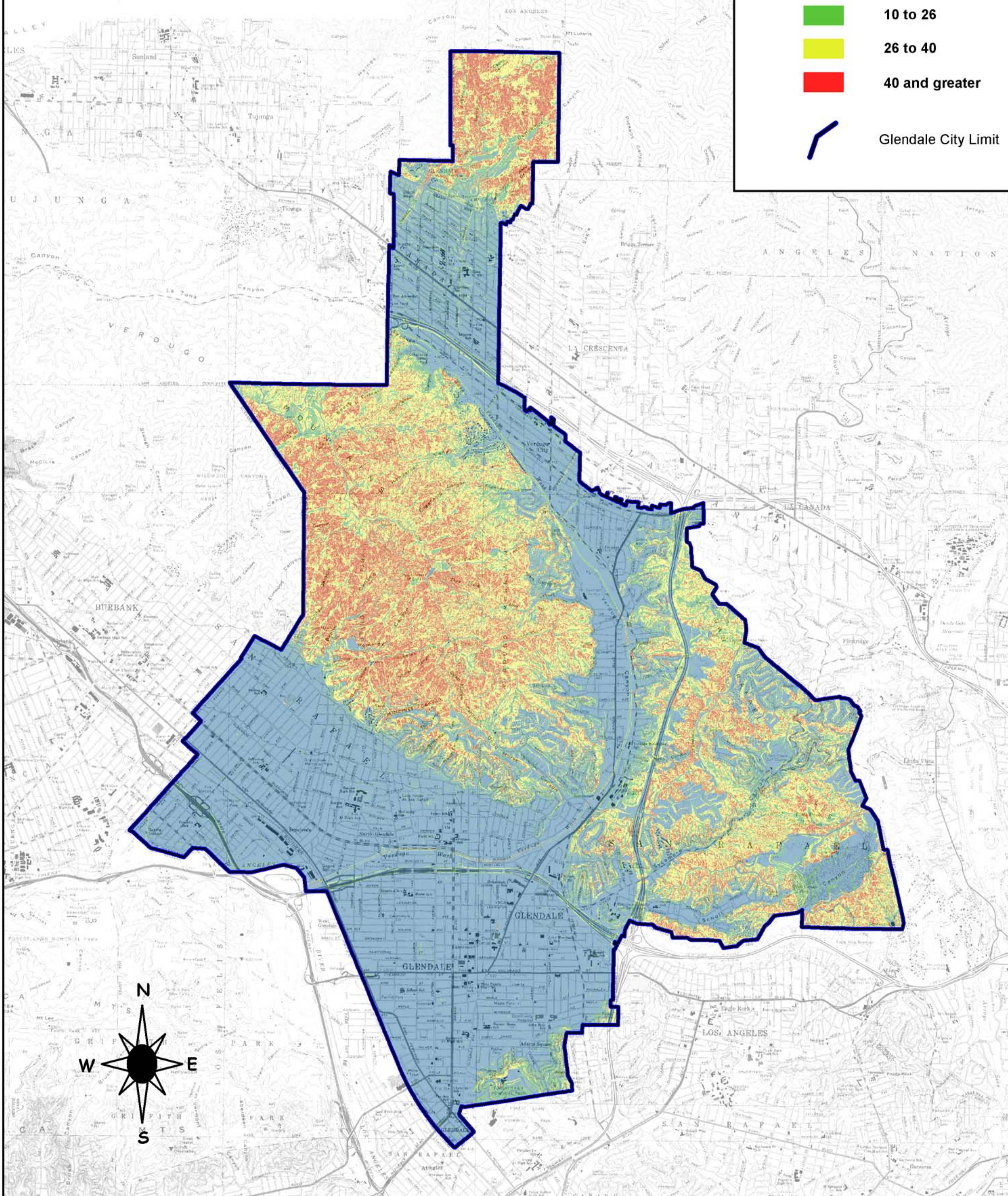

Scale: 1:60,000

1000 0 1000 2000 3000 Meters

5000 0 5000 10000 15000 Feet

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Source: Derived from City of Glendale Digital Terrain Model

Earth Consultants International

Project Number: 2103
Date: July, 2003

Slope Distribution Map

Glendale, California

Plate 2-2

NOTES:

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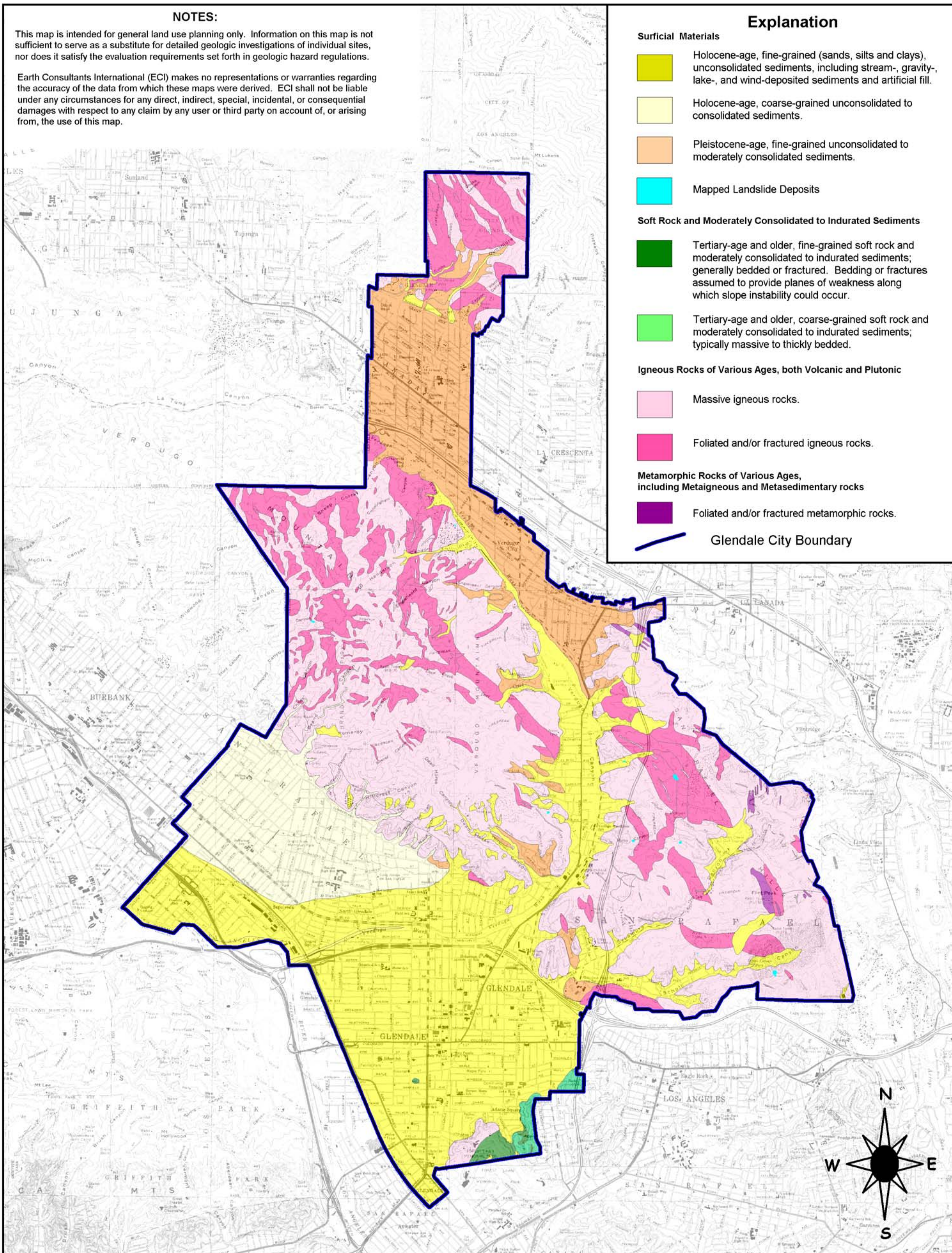


Explanation

Surficial Materials

- Holocene-age, fine-grained (sands, silts and clays), unconsolidated sediments, including stream-, gravity-, lake-, and wind-deposited sediments and artificial fill.
- Holocene-age, coarse-grained unconsolidated to consolidated sediments.
- Pleistocene-age, fine-grained unconsolidated to moderately consolidated sediments.
- Mapped Landslide Deposits

Soft Rock and Moderately Consolidated to Indurated Sediments

- Tertiary-age and older, fine-grained soft rock and moderately consolidated to indurated sediments; generally bedded or fractured. Bedding or fractures assumed to provide planes of weakness along which slope instability could occur.
- Tertiary-age and older, coarse-grained soft rock and moderately consolidated to indurated sediments; typically massive to thickly bedded.

Igneous Rocks of Various Ages, both Volcanic and Plutonic

- Massive igneous rocks.
- Foliated and/or fractured igneous rocks.

Metamorphic Rocks of Various Ages, including Metaigneous and Metasedimentary rocks

- Foliated and/or fractured metamorphic rocks.

Glendale City Boundary

Scale: 1:60,000

1000 0 1000 2000 3000 Meters

5000 0 5000 10000 15000 Feet

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Based on data from Dibblee (1989a, 1989b, 1991a, 1991b, 2002) and Byer (1968).

Earth Consultants International

Project Number: 2103
Date: July, 2003

Engineering Geologic Materials Map
Glendale, California

Plate 2-3

Soil Slip - This type of failure is generated by strong winter storms, and is widespread in the steeper slope areas, particularly after winters with prolonged and/or heavy rainfall. Failure occurs on canyon sideslopes, and in soils that have accumulated in swales, gullies and ravines. Slope steepness has a strong influence on the development of soil slips, with most generated on slopes with gradients of between 27 and 56 degrees (Campbell, 1975).

Earth flow - This type of slope failure is a persistent, slow-moving, lobe-shaped slump that typically comes to rest on the slope not far below the failure point. Earth flows commonly form in fine-grained soils (clay, silt and fine sand), and are mobilized by an increase in pore water pressure caused by infiltration of water during and after winter rains. Earth flows occur on moderate to steep slopes with gradients of between 15 and 35 degrees (Keefer and Johnson, 1983).

Rockfall – Rockfalls are free-falling to tumbling masses of bedrock that have broken off steep canyon walls or cliffs. The debris from repeated rockfalls typically collects at the base of extremely steep slopes in cone-shaped accumulations of angular rock fragments called talus. Rockfalls can happen wherever fractured rock slopes are oversteepened by stream erosion or man's activities.

Debris Flow - This type of failure is the most dangerous and destructive of all types of slope failure. A debris flow (also called mudflow, mudslide, and debris avalanche) is a rapidly moving slurry of water, mud, rock, vegetation and debris. Larger debris flows are capable of moving trees, large boulders, and even cars. This type of failure is especially dangerous as it can move at speeds as fast as 40 feet per second, is capable of crushing buildings, and can strike with very little warning. As with soil slips, the development of debris flows is strongly tied to exceptional storm periods of prolonged rainfall. Failure occurs during an intense rainfall event, following saturation of the soil by previous rains.

A debris flow most commonly originates as soil slip in the rounded, soil-filled "hollow" at the head of a drainage swale or ravine. The rigid soil mass is deformed into a viscous fluid that moves down the drainage, incorporating into the flow additional soil and vegetation scoured from the channel. Debris flows also occur on canyon walls, often in soil-filled swales that do not have topographic expression. The velocity of the flow depends on the viscosity, slope gradient, height of the slope, roughness and gradient of the channel, and the baffling effects of vegetation. Even relatively small amounts of debris can cause damage from inundation and/or impact (Ellen and Fleming, 1987; Reneau and Dietrich, 1987). Recognition of this hazard led FEMA to modify its National Flood Insurance Program to include inundation by "mudslides" (FEMA, 2001).

Watersheds that have been recently burned typically yield greater amounts of soil and debris than those that have not burned. Erosion rates during the first year after a fire are estimated to be 15 to 35 times greater than normal, and peak discharge rates range from 2 to 35 times higher. These rates drop abruptly in the second year, and return to normal after about 5 years (Tan, 1998). In addition, debris flows in burned areas are unusual in that they can occur in response to small storms and do not require a long period of antecedent rainfall. These kinds of flows are common in small gullies and ravines during the first rains after a burn, and can become catastrophic when a severe burn is followed by an intense storm season (Wells, 1987). The United States Geological Survey (USGS), as part of its National Landslide Hazards Program, is currently developing tools and methodologies to identify and quantify slope stability hazards posed by burned watersheds. Such tools will help communities with emergency planning and in dealing with post-fire rehabilitation (USGS, 2001).

OCCURRENCE OF SLOPE FAILURES IN THE GLENDALE AREA

Evidence of past slope failures are found throughout the mountain and foothill regions of the City of Glendale. The crystalline rock of the San Gabriel Mountains, weakened by fracturing, shearing, and crushing along numerous fault zones, particularly near the range front, combined with the moderate to extremely steep slopes that have resulted from rapid uplift of the mountains, are important elements that create the setting for the development of slope failures. Similar conditions are present in the Verdugo Mountains and the San Rafael Hills, where rocks are highly weathered and slope gradients of 30 degrees or steeper are common.

Significantly, however, areas of gross instability such as large deep-seated landslides have not been mapped in the Glendale area, primarily because the highly fractured crystalline rocks that underlie the San Gabriel and Verdugo Mountains and the San Rafael Hills rarely fail as large cohesive units. All of the landslides mapped within City limits are relatively small in area, and limited to the Verdugo Mountains and San Rafael Hills. The larger of these landslides are shown on Plates 2-2 and 2-4. Numerous other smaller landslides have also occurred in the area, but their size is too small to show on the maps that accompany this report. Large prehistoric landslides have been mapped in the San Gabriel Mountains just to the east of the City, but not in the Glendale area. The distribution of existing landslides in the Glendale area and vicinity was compiled from various publications, including Morton and Streitz, (1969), Crook et al. (1987), and Dibblee, (1989a, 1989b, 1991a, 1991b, 2002).

Areas of surficial instability are common along the steep slopes and canyons the San Gabriel Mountains, Verdugo Mountains and San Rafael Hills. Unfortunately detailed maps showing previous sites of surficial slope failures, such as small landslides, slumps, soil slips, and rockfalls have not been compiled or published for the Glendale area. However, an unpublished engineering geology report records several talus rockfalls on steep slopes and roadcuts in the Verdugo Mountains (R. T. Frankian & Associates, 1968). The common occurrence of rockfalls can also be inferred by the abundant talus at the base of steep slopes and in canyons of the San Gabriel Mountains.

The Southern California Area Mapping Project (SCAMP), a cooperative effort between the US Geological Survey (USGS) and the California Geological Survey (CGS), has produced a series of Debris-Flow Occurrence Maps, at a scale of 1:100,000, that predict in a general way areas that will be prone to debris flows in normally vegetated hillsides (SCAMP, 2001). The maps are based on their studies of recent El Nino events, specifically relating the relationships between rainfall thresholds, terrain, and past debris flow events. Their studies indicate that in upland areas underlain by sedimentary rock and fractured crystalline rock (such as that found in the mountains of Glendale), essentially all past debris flows have occurred on slopes with gradients of 26 degrees or steeper. The mapped debris flow susceptibility areas in the San Gabriel Mountains include most slopes steeper than 26 degrees, but do not include the heads of the large alluvial fans at the base of the mountains because the flood control dams and debris basins that have been built in these areas are thought to be adequate to contain flows from unburned areas.

However, flows can overwhelm flood control structures during periods of extreme rainfall on a recently burned hillside. For instance, during winters of exceptional rainfall (such as 1934, 1969, 1978, and 1980), debris flows caused widespread property damage and loss of life in communities in and near the base of the San Gabriel Mountains, with areas below burned watersheds receiving the bulk of the damage. For example, in November 1933, there was a large fire in the Montrose-La Crescenta area that burned more than 5,000 acres. Then, on January 1, 1934, intense rainfall fell on the same area that had burned. La Crescenta and Glendale received the brunt of the damage. Several people died, swept away by debris-laden flows that overtopped the canyons in the area. Streets were clogged with debris, and several bridges were washed out (see Plate 3-2). In 1978, several canyons within burned watersheds near the Glendale area overtopped their debris basins (Davis, 1980). These canyons include Zachau Canyon located north of Sunland, Shields Canyon north of La Crescenta, and Rubio Canyon north of Altadena. In 1980, the Rubio basin again overflowed, partially inundating one home and threatening several others (Davis, 1980). Therefore, if the right conditions are met, such as high rainfall within burned watersheds, the possibility that debris flows will overtop basins in the Glendale area cannot be precluded.

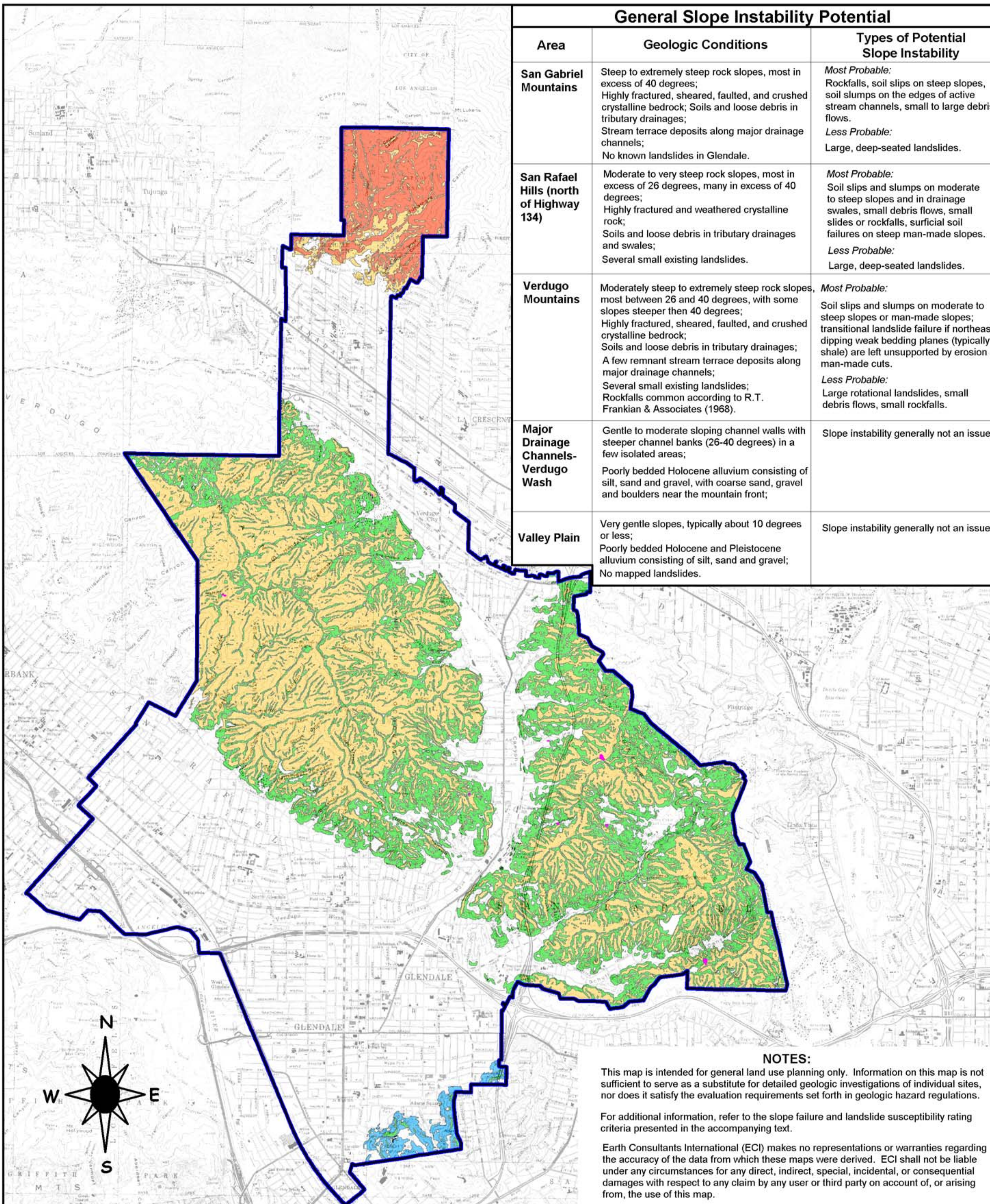
A recent detailed study of burned watersheds (including in the San Gabriel Mountains during and after the 1997-1998 winter rains) indicate that less than half of the drainage basins produced debris flows, although the debris flows that did occur were most frequently in response to the initial heavy rainfall. In addition to rainfall and slope steepness, the study highlights the many other factors that contribute to the formation of post-fire debris flows, including the underlying rock type, the shape of the drainage basin, and the presence or absence of water-repellent soils. The goal of these studies is a better understanding of the processes and conditions that generate this hazard, an understanding that is needed in order for communities to make appropriate decisions on public safety and slope mitigation (Cannon, 2001).

SUSCEPTIBILITY TO SLOPE FAILURE

The City's mountain and foothill areas are vulnerable to the types of slope instability mentioned above. Steep-sided slopes along Verdugo Wash and other incised drainages may also be locally susceptible to slope instability. Table 2-1 below is a general summary of the geologic conditions in various parts of the City that provide the environment for slope instability to occur. These conditions usually include such factors as terrain steepness, rock or soil type, condition of the rock (such as degree of fracturing and weathering), internal structures within the rock (such as bedding, foliation, faults) and the prior occurrence of slope failures. Catalysts that ultimately allow slope failures to occur in vulnerable terrain are most often water (heavy and prolonged rainfall), erosion and undercutting by streams, man-made alterations to the slope, or seismic shaking. The summary in Table 2-1 was derived from the Geologic Map (Plate 2-1), the Slope Distribution Map (Plate 2-2), and the Engineering Materials Map (Plate 2-3). The information in Table 2-1 was then used to prepare the Slope Instability Map for Glendale (Plate 2-4).

Table 2-1: General Slope Instability Potential within the City of Glendale

Area	Geologic Conditions	Types of Potential Slope Instability
San Gabriel Mountains	Steep to extremely steep rock slopes, most in excess of 40 degrees; Highly fractured, sheared, faulted, and crushed crystalline bedrock; Soils and loose debris in tributary drainages; Stream terrace deposits along major drainage channels; No known landslides in Glendale.	*Most Probable:* Rockfalls, soil slips on steep slopes, soil slumps on the edges of active stream channels, small to large debris flows. *Less Probable:* Large, deep-seated landslides.
San Rafael Hills (north of Highway 134)	Moderate to very steep rock slopes, most in excess of 26 degrees, many in excess of 40 degrees; Highly fractured and weathered crystalline rock; Soils and loose debris in tributary drainages and swales; Several small existing landslides.	*Most Probable:* Soil slips and slumps on moderate to steep slopes and in drainage swales, small debris flows, small slides or rockfalls, surficial soil failures on steep man-made slopes. *Less Probable:* Large, deep-seated landslides.
Verdugo Mountains	Moderately steep to extremely steep rock slopes, most between 26 and 40 degrees, with some slopes steeper then 40 degrees; Highly fractured, sheared, faulted, and crushed crystalline bedrock; Soils and loose debris in tributary drainages; A few remnant stream terrace deposits along major drainage channels; Several small existing landslides; Rockfalls common according to R.T. Frankian & Associates (1968).	*Most Probable:* Soil slips and slumps on moderate to steep slopes and in drainage swales, small debris flows, small slides or rockfalls, surficial soil failures on steep man-made slopes. *Less Probable:* Large, deep-seated landslides.
Major Drainage Channels – Verdugo Wash	Gentle to moderate sloping channel walls with steeper channel banks (26-40 degrees) in a few isolated areas; Poorly bedded Holocene alluvium consisting of silt, sand and gravel, with coarse sand, gravel and boulders near the mountain front; No mapped landslides.	Slope instability generally not an issue.
Valley Plain	Very gentle slopes, typically about 10 degrees or less; Poorly bedded Holocene and Pleistocene alluvium consisting of silt, sand and gravel; No mapped landslides.	Slope instability generally not an issue.



General Slope Instability Potential

Area	Geologic Conditions	Types of Potential Slope Instability
San Gabriel Mountains	Steep to extremely steep rock slopes, most in excess of 40 degrees; Highly fractured, sheared, faulted, and crushed crystalline bedrock; Soils and loose debris in tributary drainages; Stream terrace deposits along major drainage channels; No known landslides in Glendale.	*Most Probable:* Rockfalls, soil slips on steep slopes, soil slumps on the edges of active stream channels, small to large debris flows. *Less Probable:* Large, deep-seated landslides.
San Rafael Hills (north of Highway 134)	Moderate to very steep rock slopes, most in excess of 26 degrees, many in excess of 40 degrees; Highly fractured and weathered crystalline rock; Soils and loose debris in tributary drainages and swales; Several small existing landslides.	*Most Probable:* Soil slips and slumps on moderate to steep slopes and in drainage swales, small debris flows, small slides or rockfalls, surficial soil failures on steep man-made slopes. *Less Probable:* Large, deep-seated landslides.
Verdugo Mountains	Moderately steep to extremely steep rock slopes, most between 26 and 40 degrees, with some slopes steeper then 40 degrees; Highly fractured, sheared, faulted, and crushed crystalline bedrock; Soils and loose debris in tributary drainages; A few remnant stream terrace deposits along major drainage channels; Several small existing landslides; Rockfalls common according to R.T. Frankian & Associates (1968).	*Most Probable:* Soil slips and slumps on moderate to steep slopes or man-made slopes; transitional landslide failure if northeast dipping weak bedding planes (typically shale) are left unsupported by erosion or man-made cuts. *Less Probable:* Large rotational landslides, small debris flows, small rockfalls.
Major Drainage Channels-Verdugo Wash	Gentle to moderate sloping channel walls with steeper channel banks (26-40 degrees) in a few isolated areas; Poorly bedded Holocene alluvium consisting of silt, sand and gravel, with coarse sand, gravel and boulders near the mountain front;	Slope instability generally not an issue.
Valley Plain	Very gentle slopes, typically about 10 degrees or less; Poorly bedded Holocene and Pleistocene alluvium consisting of silt, sand and gravel; No mapped landslides.	Slope instability generally not an issue.

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For additional information, refer to the slope failure and landslide susceptibility rating criteria presented in the accompanying text.

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Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Derived from Dibblee, 1989a, 1989b, 1991a, 1991b, 2002; Byer, 1968 and United States Geological Survey 10-meter Digital Elevation Model.

Scale: 1:64,000

1 0 1 2 3 Kilometers

0.5 0 0.5 1 1.5 Miles

EXPLANATION

Mapped Landslides (small isolated areas in the Verdugo Mountains and the San Rafael Hills.)

Glendale City Boundary

Slope Instability Rating

- Very High
- High
- Moderate
- Low

Earth Consultants International

Project Number: 2103
Date: July, 2003

Slope Instability Map

Glendale, California

Plate 2-4

MITIGATION OF SLOPE INSTABILITY IN FUTURE DEVELOPMENT

All proposed projects require a site-specific geotechnical evaluation of any slopes that may impact the future use of the property. This includes existing slopes that are to remain, and any proposed graded slopes. The investigation typically includes borings to collect geologic data and soil samples, laboratory testing to determine soil strength parameters, and engineering calculations. Numerous soil engineering methods are available for stabilizing slopes that pose a threat to development. These methods include designed buttresses (replacing the weak portion of the slope with engineered fill); reducing the height of the slope; designing the slope at a flatter gradient; and adding reinforcements such as soil cement or layers of geogrid (a tough polymeric net-like material that is placed between the horizontal layers of fill). Most slope stabilization methods include a subdrain system to remove excessive ground water from the slope area. If it is not feasible to mitigate the slope stability hazard, building setbacks are typically imposed.

For debris flows, assessment of this hazard for individual sites should focus on structures located or planned in vulnerable positions. This generally includes canyon areas; at the toes of steep, natural slopes; and at the mouth of small to large drainage channels. Mitigation of soil slips, earthflows, and debris flows is usually directed at containment (debris basins), or diversion (impact walls, deflection walls, diversion channels, and debris fences). A system of baffles may be added upstream to slow the velocity of a potential debris flow. Other methods include removal of the source material, placing subdrains in the source area to prevent pore water pressure buildup, or avoidance by restricting building to areas outside of the potential debris flow path.

There are numerous methods for mitigating rock falls. Choosing the best method depends on the geological conditions (i.e., slope height, steepness, fracture spacing, bedding orientation), safety, type and cost of construction repair, and aesthetics. A commonly used method is to regrade the slope. This ranges from locally trimming hazardous overhangs, to completely reconfiguring the slope to a more stable condition, possibly with the addition of benches to catch small rocks. Another group of methods focuses on holding the fractured rock in place by draping the slope with wire mesh, or by installing tensioned rock bolts, tie-back walls, or even retaining walls. Shotcrete is often used on the slope face to prevent raveling in highly fractured rock, but its primary purpose is to offer surface protection only. A third type of mitigation includes catchment devices at the toe of the slope, such as ditches, walls, or combinations of both. Designing the width of the catchment structure requires analysis of how the rock will fall. For instance, the slope gradient and roughness of the slope determines if rocks will fall, bounce, or roll to the bottom. Rock slope stabilization may also include the addition of drains in order to reduce water pressure within the slope (Wyllie and Norrish, 1996).

MITIGATION OF SLOPE INSTABILITY IN EXISTING DEVELOPMENT

There are a number of options for management of potential slope instability in developed hillsides.

- Complete a detailed survey and assessment of existing developments in areas recognized to be vulnerable to potential slope failures (for instance, the Verdugo Mountains, the San Rafael Hills, and at the base of the San Gabriel Mountains).

- Protect existing development and population where appropriate by physical controls such as drainage, slope-geometry modification, protective barriers, and retaining structures.
- Implement monitoring or warning systems. For instance in the San Francisco Bay area, the USGS, in cooperation with the National Weather Service, operated a system for real-time warnings for storm-related slope failures (Keefer et al., 1987). Using a combination of tracking storm systems, measuring actual rainfall with a network of rain gauges, and comparing thresholds for the initiation of debris flows, they were able to issue Flash Flood/Debris Watches during the most intense storms (Wilson, 1997). This would be especially valuable for developments adjacent to burned watersheds.
- Post warning signs in areas of potential slope instability
- Encourage homeowners to use landscaping methods that help stabilize the hillsides.
- Incorporate recommendations for potential slope instability into geologic and soil engineering reports for additions and new grading.
- Educate the public about slope stability, including the importance of maintaining drainage devices. USGS Fact Sheet FS-071-00 (May, 2000) and the CGS Note 33 (November, 2001) provide public information on landslide and mudslide hazards. These are available on the internet (see Appendices A and B).

2.4.2 Collapsible Soils

In soil engineering terminology, collapse occurs when saturated soils undergo a rearrangement of their grains and a loss of cementation, resulting in substantial and rapid settlement under relatively low loads. An increase in surface water infiltration, such as from irrigation, or a rise in the groundwater table, combined with the weight of a building or structure, can initiate rapid settlement and cause foundations and walls to crack. In the Glendale area, the most likely occurrence of collapsible soils is at the bottoms of the modern drainage channels, such as the Verdugo Wash, and at the base of the mountains, where talus and other loose sediments that were deposited rapidly by gravity have accumulated.

MITIGATION OF COLLAPSIBLE SOILS

The potential for soils to collapse should be evaluated on a site-specific basis as part of the geotechnical studies for development. If the soils are determined to be collapsible, the hazard can be mitigated by several different measures or combination of measures, including excavation and recompaction, or pre-saturation and pre-loading of the susceptible soils in-place to induce collapse prior to construction. After construction, infiltration of water into the subsurface soils should be minimized by proper surface drainage design, which directs excess runoff to catch basins and storm drains, and away from the building foundations.

2.4.3 Expansive Soils

Fine-grained soils, such as silts and clays, may contain variable amounts of expansive clay minerals. These minerals can undergo significant volumetric changes as a result of changes in moisture content. The upward pressures induced by the swelling of expansive soils can have significant harmful effects upon structures and other surface improvements.

Most of the Glendale area is underlain by alluvial units that are composed primarily of granular soils (silty sand, sand, and gravel). Such units are typically in the low to moderately low range for expansion potential. However, every sedimentary unit in the area contains lenses or layers of fine-grained soils (clays and silty clays) that are typically in the moderate to highly expansive range. Such sediments are most likely to be found in the more distal parts of the alluvial fans, in the southern part of the City.

Expansive clay can also be found within fault and fracture zones in the highly sheared crystalline bedrock of the San Gabriel and Verdugo Mountains and in the San Rafael Hills. These tabular and lensoidal zones of clay often form due to alteration of bedrock during fault movement. Clay can also be deposited along bedrock fractures by ground water. The clay zones lining faults and fractures can be up to several feet thick.

Potentially expansive layers, including clay zones along faults and fractures, may be exposed at the surface by erosion, or may be uncovered during grading, in cuts made for developments. In some cases, engineered fills may be expansive and cause damage to improvements if such soils are incorporated into the fill near the finished surface. Structures placed directly on clay beds or clay-rich zones may experience structural distress as a result of expansion of the clay minerals in a vertical (upward) direction.

MITIGATION OF EXPANSIVE SOILS

The best defense against this hazard in new developments is to avoid placing expansive soils near the surface. If this is unavoidable, building areas with expansive soils are typically "presaturated" to a moisture content and depth specified by the soil engineer, thereby "pre-swelling" the soil prior to constructing the structural foundation or hardscape. This method is often used in conjunction with strong foundations that can resist small ground movements without cracking. Good surface drainage control is essential for all types of improvements, both new and old. Property owners should be educated about the importance of maintaining relatively constant moisture levels in their landscaping. Excessive watering, or alternating wetting and drying, can result in distress to improvements and structures.

2.4.4 Ground Subsidence

Ground subsidence is the gradual settling or sinking of the ground surface with little or no horizontal movement. Most ground subsidence is man-induced. In the areas of southern California where significant ground subsidence has been reported (such as Antelope Valley, Murrieta, and Wilmington, for example) this phenomenon is usually associated with the extraction of oil, gas or ground water from below the ground surface.

Ground-surface effects related to regional subsidence can include earth fissures, sinkholes or depressions, and disruption of surface drainage. Damage is generally restricted to structures sensitive to slight changes in elevations, such as canals, levees, underground pipelines, and drainage courses; however, significant subsidence can result in damage to wells, buildings, roads, railroads, and other improvements. Subsidence has largely been brought under control in affected areas by good management of local water supplies, including reducing pumping of local wells, importing water, and use of artificial recharge (Johnson, 1998; Stewart et al., 1998).

No regional subsidence as a result of groundwater pumping has been reported in the literature for the Glendale area. However, the thick alluvial deposits underlying the City may be susceptible to subsidence should rapid groundwater withdrawal occur beneath this portion of the groundwater basin in response to an increasing population.

MITIGATION OF GROUND SUBSIDENCE

Subsidence prevention requires a regional approach to groundwater conservation and recharge. In the Antelope Valley, some the measures that have been proposed or implemented to manage subsidence (Galloway et al., 1998) include:

- Increase use of reclaimed water, storm water, and imported water;
- Implement artificial recharge programs;
- Determine the safe yields of the groundwater basins, so that the available supplies can be balanced with groundwater extraction;
- Monitor the groundwater and publish annual reports on basin conditions;
- Protect groundwater quality;
- Reduce long-term water demand with specific programs of water conservation;
- Acquire additional imported water supplies; and
- Encourage water conservation through public education.

2.4.5 Radon Gas

Radon is a colorless, odorless, radioactive gas. The most common source of indoor radon is uranium in the soil or rock on which homes are built. As uranium naturally breaks down, it releases radon gas, which enters homes through dirt floors, cracks in concrete walls and floor, floor drains, and sumps. Exposure to radon becomes a concern if the radon becomes trapped in buildings and concentrations build up indoors. Sometimes radon enters homes through well water. In a small number of homes, the building materials can give off radon too, although building materials rarely cause radon problems by themselves.

Health Effects and Risk from Exposure to Radon - There are no immediate symptoms associated with exposure to radon. The main health effect associated with exposure to elevated levels of radon is an elevated risk of developing lung cancer. The EPA estimates that radon causes about 14,000 deaths per year in the United States, although this number could range from 7,000 to 30,000 deaths per year (http://www.epa.gov/iaq/pubs/insidest.html).

Radon Potential - The United States Environmental Protection Agency (EPA) and the United States Geological Survey (USGS) have evaluated the radon potential in the United States and have developed maps to assist national, state and local organizations to target their resources and to assist building code officials in deciding whether radon-resistant features are applicable and justifiable in new construction. These maps can be viewed at the following website: http://www.epa.gov/iaq/radon/zonemap.html.

Each county in the United States is assigned to one of three zones based on radon potential. The zone designations are based on the average short-term radon measurement that can be expected to be measured in a building without the implementation of radon control methods. The Zone 1 designation indicates the highest potential for radon gas, Zone 2 a moderate potential, and Zone 3 a low potential. However, the EPA notes that these maps are not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones and therefore, the EPA recommends that all homes be tested regardless of geographic location. Any home may have a radon problem, including new or old homes, well-sealed or drafty homes, and homes with or without basements. The EPA also recommends consulting the EPA Map of Radon Zones document (EPA-402-R-93-071) before using the website map. EPA regional radon contacts are listed on the following website: http://www.epa.gov/iaq/regionia.html.

Table 2-2: Radon Health Risk If You Smoke or If You Have Never Smoked

RADON RISK IF YOU SMOKE			
Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime …	The risk of cancer from radon exposure compares to …	WHAT TO DO: Stop smoking and …
20 pCi/L	About 135 people could get lung cancer	100 times the risk of drowning.	Fix your home.
10 pCi/L	About 71 people could get lung cancer	100 times the risk of dying in a home fire.	Fix your home.
8 pCi/L	About 57 people could get lung cancer		Fix your home.
4 pCi/L	About 29 people could get lung cancer	100 times the risk of dying in an airplane crash.	Fix your home.
2 pCi/L	About 15 people could get lung cancer	2 times the risk of dying in a car crash.	Consider fixing between 2 and 4 pCi/L.
1.3 pCi/L	About 9 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level).	(Reducing radon levels below 2 pCi/L is difficult.)
Note: If you are a former smoker, your risk may be lower.			

RADON RISK IF YOU HAVE NEVER SMOKED			
Radon Level	If 1,000 people who never smoked were exposed to this level over a lifetime …	The risk of cancer from radon exposure compares to …	WHAT TO DO:
20 pCi/L	About 8 people could get lung cancer	The risk of being killed in a violent crime.	Fix your home.
10 pCi/L	About 4 people could get lung cancer		Fix your home.
8 pCi/L	About 3 people could get lung cancer	10 times the risk of dying in an airplane crash.	Fix your home.
4 pCi/L	About 2 people could get lung cancer	The risk of drowning.	Fix your home.
2 pCi/L	About 1 person could get lung cancer	The risk of dying in a home fire.	Consider fixing between 2 and 4 pCi/L.
1.3 pCi/L	Less than 1 person could get lung cancer	(Average indoor radon level).	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	Less than 1 person could get lung cancer	(Average outdoor radon level).	(Reducing radon levels below 2 pCi/L is difficult.)
Note: If you are a former smoker, your risk may be higher.			

Source: http://www.epa.gov/cgi-bin/epaprintonly.cgi

The EPA Map of Radon Zones and other indoor air quality publications can be ordered from the following sources:

- IAQ INFO
  P.O. Box 37133
  Washington, D.C. 20013-7133
  1-800-438-4318 or 703-356-4020
  iaqinfo@aol.com

- EPA's National Service Center for Environmental Publications (NSCEP)
  http://www.epa.gove/ncepihom/

- U.S. Environmental Protection Agency
  National Center for Environmental Publications (NSCEP)
  P.O. Box 42419
  Cincinnati, OH 42419
  1-800-490-9198 or 513-489-8695 (FAX)

Radon and Real Estate - The Environmental Protection Agency (EPA) has developed a number of tools and resources to be used by the real-estate community. There is a new video, *Breathing Easy: What Home Buyers and Sellers Should Know about Radon Gas*. It gives information on how to best include radon in residential real estate transactions. The video covers the radon science, the lung cancer risk, home inspection, building a new radon-resistant home, testing and fixing a home, disclosure, State radon offices, hotline and web resources, and key radon numbers (e.g., EPA's action level and the U.S. indoor and outdoor averages). The video was developed for use by homebuyers and sellers, and real estate sales agents and brokers. Home inspectors, mortgage lenders, other real estate practitioners, and radon services providers will also find the video helpful. Single copies of the video are free from IAQ-Info (1-800-438-4318) in VHS format [ask for EPA 402-V-02-003 TRT 13.10]; copies in CD-ROM and DVD formats will also be available soon.

The following resources are also available from the EPA:

- Revised Home Buyer's and Seller's Guide to Radon (EPA Publication 402-K-00-008, updated in July, 2000). This publication is also available in Spanish (www.epa.gov/iaq/pubs/hmbyguidsp.html);
- Financing Residential Radon Mitigation Costs: the HUD 203(k) Mortgage Insurance Program;
- American Society of Home Inspectors (ASHI) Radon Mitigation System Inspection Checklist; and
- How to Find a Qualified Radon Service Professional in Your Area.

Hazard Analysis and Mitigation - The County of Los Angeles, and therefore the City of Glendale, are located in Zone 2, which has a "Moderate Potential" for radon gas (http://www.epa.gov/iaq/radon/zonemap/california.htm). Zone 2 counties have a predicted average indoor radon screening level between 2 and 4 pCi/L (picoCuries per liter). However, you cannot predict radon levels based on state, local and neighborhood radon measurements. Testing is the only way to know if you are at risk from radon. The EPA and the Surgeon General recommend testing all homes below the third floor for radon (http://www.epa.gov/iaq/radon/pubs/hmbyguid.html). In addition, the EPA recommends that homebuyers and sellers do the following:

- If you are buying or selling your home, have it tested for radon.
- For a new home, ask if radon-resistant construction features were used and if the house has been tested.
- Fix the home if the radon level is 4 pCi/L, or higher.
- Radon levels less than 4 pCi/L still pose a risk, and in many cases, may be reduced.
- Prevent device interference when conducting a radon test.

California law requires professional providers of radon services to be certified. It is strongly recommended to hire a disinterested third-party to assure the validity of the testing. The State of California maintains a list of certified providers of radon services and one of the groupings for certification is "testers." Certified Radon Testers conduct radon measurements in residential structures, commercial structures, and occupational settings.

The California Department of Health Services Radon program is currently offering free short-term radon test kits available for persons interested in determining the radon level in the indoor air of their homes. These radon test kits can be used to screen your home prior to offering it for sale to determine if the radon levels may be an issue or a concern. In order to obtain a free short-term radon test, you can contact the phone numbers or addresses below, providing your name, address and phone number. The Radon Program staff will send you informational materials and a test kit. It is important to note however, that the test kits are NOT to be used for determining the radon levels in your home as part of a real estate transaction.

For more information regarding radon, or if you have questions regarding radon in the State of California, contact:

Radon Program, http://www.dhs.ca.gov/radon
Department of Health Services
Environmental Management Branch
601 North 7th Street, MS 396
P.O. Box 942732
Sacramento, CA 94234-7320
Fax (916) 324-1380
Radon Hotline 1-(800)-745-7236

How to Find a Qualified Radon Service Professional in Your Area - Contact your **State Radon Contact** (http://www.epa.gov/iaq/whereyoulive.html) to determine the requirements, if any, associated with providing radon measurement and or radon mitigations/reductions in your State. Some States maintain lists of contractors available in their state or they have proficiency programs or requirements of their own.

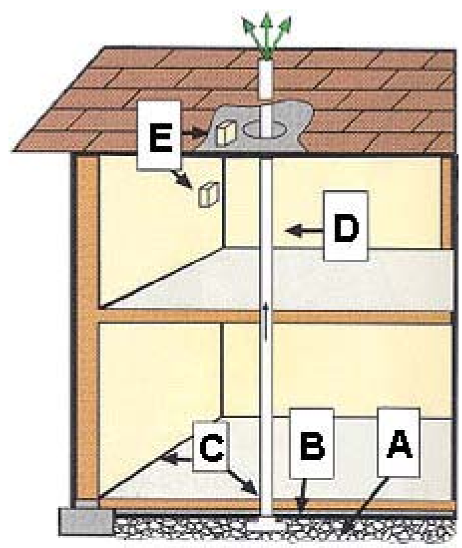
Inspection Checklist - The American Society of Home Inspectors (ASHI) along with the EPA's Indoor Environments Division have created a **Radon Mitigation System Inspection**

Checklist (**http://www.epa.gov/iaq/radon/images/ashicklst.pdf**). The main purpose of this checklist is to educate home inspection clients about radon, and to encourage radon testing and mitigation when radon levels of 4pCi/L or more are found. The *Checklist* promotes radon awareness, testing and mitigation for people who are having their home or prospective home, inspected. The *Checklist* has seven inspection elements and should take under 15 minutes to complete. Inspectors can easily integrate it into a general home inspection. The inspection results indicate whether the home has a mitigation system, and if so, whether the system is active or passive. It also encourages the consumer to verify that indoor radon levels are below 4 pCi/L, and to consult a qualified mitigator if the inspection notes any apparent deficiencies.

Radon Mitigation - If your radon test result is 4 pCi/L or higher, the EPA recommends that action be taken to reduce the indoor radon level. Various methods can be used to reduce radon in homes. One method is sealing cracks and openings in the foundation. However, the EPA does not recommend the use of sealing alone to limit radon entry, as it has not been shown to lower radon levels significantly or consistently. For most homes, a system with a vent pipe and fan is used, however the correct system depends on home design and other factors. The EPA provides techniques for reducing radon in its publication "Consumer's Guide to Radon Reduction." The basic elements are:

Figure 2-1: Radon Construction Mitigation

<table>
<tr><td>A. Gas Permeable Layer

This layer is placed beneath the slab or flooring system to allow the soil gas to move freely underneath the house. In many cases, the material used is a 4-inch layer of clean gravel.</td><td rowspan="3">
</td></tr>
<tr><td>B. Plastic Sheeting

Plastic sheeting is placed on top of the gas permeable layer and under the slab to help prevent the soil gas from entering the home. In crawlspaces, the sheeting is placed over the crawlspace floor.</td></tr>
<tr><td>C. Sealing and Caulking

All openings in the concrete foundation floor are sealed to reduce soil gas entry into the home.</td></tr>
<tr><td colspan="2">D. Vent Pipe

A 3- or 4-inch gas-tight or PVC pipe (commonly used for plumbing) runs from the gas permeable layer through the house to the roof to safely vent radon and other soil gases above the house.</td></tr>
<tr><td colspan="2">E. Junction Box

An electrical junction box is installed in case an electric venting fan is needed later.</td></tr>
</table>

Source: http://www.epa.gov/iag/radon/construc.html

2.5 Summary

The City of Glendale is situated on the alluvial surfaces and mountainous regions of the southeastern San Fernando Valley. The alluvial surfaces blanket the flanks and fill the intervening valleys and drainages between the San Gabriel Mountains and the Verdugo Mountains, and between the Verdugo Mountains, the San Rafael Hills and the eastern extension of the Santa Monica Mountains (locally known as the Hollywood Hills). Geologic units within the City consist of poorly or crudely stratified sand, silt, and gravel in the lowlands, with dense crystalline rock forming most of the hillsides. The hills in the southeastern portion of the City are composed of stratified sedimentary rocks, typically sandstone, conglomerate and shale.

The City's hillsides are vulnerable to slope instability due primarily to the fractured, crushed and weathered condition of the bedrock, and the steep terrain. Oversteepened slopes along the large drainage channels are also locally susceptible. The probability of large bedrock landslides occurring is relatively low, therefore the source of potential losses due to slope instability arises primarily from the occurrence of smaller slope failures in the form of small slides, slumps, soil slips, debris flows and rockfalls. The initiation of such failures is generally tied to a preceding event, such as wildfire, heavy winter storms, seismic activity, or man's activities.

Although the mountainous terrain within the San Gabriel Mountains has been dedicated to parks and recreation, residential development is present within the steep slopes of the Verdugo Mountains and the San Rafael Hills. The Uniform Building Code and the City's hillside grading ordinance provide standards by which slope stability in new developments (including the required geologic and soils investigations) can be effectively managed, provided these requirements are strictly enforced. This process should include geotechnical third-party review by a California-registered engineering geologists and soil engineers. The majority of the City's buildable hillsides are already developed. Some of the older structures in these areas were built prior to development of modern grading codes, regulations and practices, and may therefore be at risk, especially if located at the top or the toe of steep slopes (generally those steeper than 26 degrees), at the mouth of gullies, swales or ravines. Structures built in areas adjacent to or in potential wildfire areas are particularly susceptible to slope damage during wet winters following wildland fires.

Both the USGS and the CGS are currently conducting significant research that focuses on the conditions and processes that lead to destructive slope failures. This includes methodology for analysis of slopes and drainage basins, and the development of susceptibility maps. Detailed maps prepared by either of these agencies showing the prior occurrence of slope failures in the Glendale area, as well as local susceptibility, are not yet available. Plate 2-2 shows the slope instability areas identified for the Safety Element update, based on slope angle and soil and rock conditions.

The alluvial deposits in floors of major drainage channels are susceptible to liquefaction (see Section 1.7) and possibly collapse. For mitigation measures that can be implemented to reduce the liquefaction hazard, refer to Chapter 1. In areas proposed for development, site-specific studies need to be conducted to evaluate the settlement potential of the underlying soils. These geotechnical studies should evaluate the collapse potential of the entire soil column within the effective depth of infiltration of irrigation water, instead of only the near-surface soils.

Some of the geologic units in the Glendale area have fine-grained components that are moderately to highly expansive. These units are generally present in all the low-lying areas within Glendale, where fine-grained sequences within the alluvial fans are more likely to be present. Expansive materials are also present in clay-lined fault and fracture zones throughout the highly sheared crystalline rock of the

San Gabriel and Verdugo Mountains and the San Rafael Hills. These fine-grained units may not be present at the surface but may be exposed during grading. The presence of potentially expansive soils should be assessed for every project, on a lot-by-lot basis, with engineering solutions implemented as needed.

There are no immediate symptoms associated with exposure to radon gas. The main health effect associated with exposure to elevated levels of radon gas is an elevated risk of developing lung cancer. Testing is the only way to know if you are at risk from radon gas. The California Department of Health Services (DHS) and the United States Environmental Protection Agency have programs to increase public awareness of radon risks, radon testing and mitigation of radon gas risks. Their websites provide a wealth of information. It is recommended that City of Glendale residents, buyers and sellers of residential property, realtors and business owners contact these governmental agencies for additional information and resources. It is also recommended that the City of Glendale play a more active role in educating its residents about the hazards posed by radon gas and the sources of radon gas information and resources available.